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THE CATSKILL WATER SUPPLY SYSTEM[1]

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Organization. At the time of the inauguration of the McClellan administration, the fact that the consumption of water by the city of New York was rapidly approaching the limits of the existing supply had been pretty well demonstrated by several investigations conducted by the department of water supply, gas and electricity, by John R. Freeman's report to the comptroller in 1900, and by the Burr-Hering-Freeman commission in 1903. Mayor McClellan, with characteristic energy and thoroughness, reviewed all these reports and satisfied himself that it was necessary for the city to secure at once an additional supply of water, and, although other municipal improvements were put forward as necessary and advisable, he chose that of water supply as being most vital to the city's interest and the one which most demanded prompt attention. In the beginning of the second year of his first administration he secured the necessary legislation to make it practicable to proceed at once to determine the best sources from which to obtain an additional water supply and for its construction after the plans were approved.

It had been the uniform custom of the city of New York, when any great improvement was to be carried out, to put it in the hands of a special commission vested with broader powers than those possessed by any of the coördinated departments of the city government, in order that such special work might be more effectively and expeditiously carried out. This precedent was followed, and a board of

[1] Read before the New York Section on October 18, 1917.

water supply, composed of three commissioners, was selected by Mayor McClellan, on the recommendations of certain civic organizations. The statute contained a stipulation that the commissioners could be removed only on account of incompetence or misconduct, proved by hearing after due notice upon stated charges. This provision was designed to insure continuance in office during good behavior and to prevent the change of commissioners with each new city administration. The plan has worked admirably. No commissioner has been removed throughout the progress of the work to date, and only two have resigned, one to retire from active work and one to fill an important state office.

The board appointed the chief engineer. All other appointments in the engineering bureau, as well as dismissals and promotions, have been made by the board in accordance with the chief engineer's recommendations. In no case has a commissioner sought to control or influence these recommendations. This may seem somewhat remarkable in a city which has been so much maligned as the city of New York in past years. This maligning is often done by its own citizens, who, in lecturing throughout the country from time to time, attempt to appeal to the popular prejudice that all public employees are incompetent or dishonest, and make the most astounding statements, with no knowledge of the facts and without even trying to learn them. The author doubts if any other public improvement—national, state or municipal—throughout the country can show a better record.

Preparation and approval of general plan. The chief engineer's appointment took place on August 1, 1905, and a small corps of engineers, about 27, were available by September 1.

The first work in hand was the preparation of a general plan covering an additional supply of water by gravity to the five boroughs of the city. It did not seem advisable to make additional extended investigations as to sources of water supply. Previous investigations and legislative action had pretty well fixed those which might be developed. By utilizing all the information available, and by close application and great energy on the part of the small working force, which was increased to 55 during the month of September, within the space of about five working weeks reconnaisance surveys had been made and a complete plan, including estimates, was prepared, excepting the major part of its delivery system within the city. This plan was approved by the board of water supply and submitted

on October 9 to the board of estimate and apportionment for approval. With the exception of some minor modifications this is the plan which has been carried out. The original estimate, exclusive of the part of the delivery system which was omitted, was $162,000,000. A year or two later studies for the delivery system were completed, and the additional cost estimated at $15,000,000, making the estimate for the entire work $177,000,000. This estimate was made with practically no subsurface investigation. Although there have been many changes in legislation, such as the 8-hour law, the law providing for the establishment of the aqueduct police, and the provision for the payment of indirect and business damages, all of which tended to add to the cost, in an amount estimated to be from $8,000,000 to $20,000,000, it is believed that the work will be completed within the original estimate. As the matter stands today, the actual disbursements and liabilities are $139,000,000. A liberal estimate for completing the unfinished work is $37,000,000, making a total of $176,000,000, or $1,000,000 less than the original estimate, without allowing any credit for the additional expense imposed by legislation.

The approval of the board of estimate and apportionment was secured within the minimum statutory limit of two weeks, and it then remained to obtain the approval of the state water supply commission, which was created simultaneously with the board of water supply and was given general supervision over the sources of water supply to be chosen. Application to the commission was made promptly, and hearings were held, extending over six months. After securing additional legislation to cover indirect and business damage and police protection the general plan was approved by the state water supply commission, in June, 1906, thus making it possible to proceed with the surveys and investigations necessary for the preparation of the construction contracts.

Prosecution of work under contract. The construction contracts were put forward rapidly, so that the first contract, for 11 miles of aqueduct in the vicinity of Peekskill, was awarded in March, 1907. The largest contract on the entire work, that for the main dams of the Ashokan reservoir, of a value of over $12,500,000, was awarded in August of the same year. Other contracts were prepared as rapidly as possible, so that all those involving a large volume of work outside the city were operative before the end of 1909. The main contracts for the delivery of water within the city were awarded in 1911.

Delivery of water to the city. The first water was actually delivered to the city on December 27, 1915, and thereafter a small quantity was delivered throughout that winter and intermittently during 1916. The general delivery of water to all boroughs began in January, 1917. The first delivery of water was made at least a year sooner than was anticipated, and it would have been possible at any time since April, 1913, to deliver water for an emergency period through the Croton aqueduct, had necessity arisen.

Working force and expenditures. The maximum force in the engineering bureau at any time was 1348, in 1911. The maximum labor force employed on all contracts at one time was 16,229 in the same year. The largest expenditure in any month was $3,900,000, in June, 1911, and for one year was $25,900,000 in 1911.

Completion of contracts. The following facts are pertinent. All the construction work, about $100,000,000 in value, has been accomplished by the original contractors or their legal representatives, without the intervention of the city or a call on a surety company to advance money. The author wishes it could be said that the contractor had made a fair profit in every case, but this is probably too much to expect. Difficulties were encountered, due in some cases to low bids, and in other cases due to failure of the contractor to adopt the best methods for doing the work. That the latter was the fact in some cases was very plainly brought out by the operation of contiguous contracts, for the same class of work under approximately the same working conditions, where one contractor, at a lower price, has made a handsome profit, while another, at a higher price, broke even or made a small profit, and in some cases operated at a large loss.

None of the contracts contained provisions for doing work other than that directly provided for in the items of the contract. While it is believed that there should be in contracts provisions for doing extra and additional work, with suitable safeguards, in order to afford greater elasticity, such provisions were debarred by the representatives of the law department. In spite of this handicap, the work was accomplished without the embarrassment of having to suspend operations on a single contract in order to have work done which had not been anticipated or provided for.

Completion within estimated cost. The amounts paid under all the construction contracts, aggregating $100,000,000 in value, averaged approximately 5 per cent less than the amount bid. This is not

claimed to be a saving, as some have tried to make it appear. Nevertheless, it has had a good effect on the public mind because the dear public is prone to consider that any additional expense over the amount bid on a contract is due to incompetence in the preparation or to collusion on the part of those executing it and that such excess is always an increase in the cost. As a matter of fact, we know that the actual cost is neither increased nor decreased.

Importance of preliminary investigations. Believing that very thorough investigations were absolutely essential as a preliminary to the preparation of contracts for construction work and that failure or serious complications are quite frequently due to lack of such preparation special effort was made to have the preliminary inevestigations as thorough and exhaustive as was consistent with economy. Investigations in connection with the location of the dams and of the aqueduct line required the making of 14 miles in depth of wash borings, 31 miles in depth of core borings, the excavating of numerous test shafts and trenches and the making of 3400 miles of preliminary surveys. All this information was exhaustively studied and analyzed. This thoroughness was all the more essential for the preparation of contracts in which there could be no provision for doing other work than that specifically provided for under the items of the contract. The contract and specifications, in the course of their preparation, went through the hands of the most skilled workers in headquarters, and they were also particularly examined by the engineers in the field, who would execute the work, before being put into permanent shape. It was due to this carefulness, and this alone, that it was possible to conduct the whole work, a large part of which was prosecuted under the surface of the ground, without meeting any unforeseen difficulties which had not been anticipated and provided for. Many an undertaking has been wrecked, or seriously hampered, by untimely haste in beginning work, before thorough preparation was made, in response to the popular demand for the "dirt to fly." Due to the great business activity during the early years of the work, or to some kind Providence, this misfortune was averted. The contracts and specifications, as prepared, were intended to give the fullest information to bidders. No attempt was made to conceal or belittle any of the difficulties which were anticipated; instead, an effort was made to emphasize them, and the men in field were instructed to call the attention of prospective bidders to any physical condition

which would affect the execution of the work or the prices to be bid.

Payment items. The contracts contained specific payment items for much work usually included in general expense, and an effort was made to provide a payment item for all work which could be reasonably segregated and measured. The work included in each item and the method of measurement and payment for same were carefully set forth, with the intent of preparing contracts and specifications, which, so far as possible, would eliminate controversies and differences of opinion. This could be successfully done to only a limited degree, for it is impossible to write in this language so that it will be interpreted in the same way by all readers.

Construction of dams in sections, with drainage systems. The building of the dams in sections, with transverse joints about 80 feet apart, has prevented cracking through the body of the masonry on account of contraction, and has incidentally served as an aid to construction, both as to safety and convenience. The masonry between the borders of the drainage system is so impervious that it is uncertain whether this drainage system would be effective or not. As a matter of fact, practically no water runs into it except at the expansion joints. From this experience the author is inclined to eliminate the main drainage system and retain the building in sections.

Construction of steel-pipe siphons. In constructing the steel-pipe siphons, the plates were first pickled to remove all the mill scale before fabrication at the shop. In the field the pipe was laid on concrete saddles carefully set to grade, and after a siphon was completed and full pressure was applied the pipe was completely surrounded with concrete of sufficient thickness to prevent deformation when empty. The pipe was then unwatered and 2 inches of cement mortar placed on the inside. This was accomplished by setting up forms inside the pipe and placing a 1:1 grout around the forms. This resulted in an exceedingly smooth lining, which, up to date, has shown no tendency toward loosening from the pipe. It is believed that this pipe is more completely preserved than by any bitumen coatings previously applied. It certainly provides a much smoother inner surface.

Pressure tunnels. Pressure tunnels are not new. As long ago as the construction of the Croton aqueduct, a pressure tunnel was built from a point north of Jerome Park reservoir to the reservoir

at 135th Street, including the crossing under the Harlem River in the neighborhood of Highbridge. The only marked difference between that pressure tunnel and those constructed on the Catskill work is that the maximum pressure in the case of the Croton was only a little over that due to 100 feet head and that for most of the distance the hydraulic grade was below the level of the ground, or slightly above it, whereas for the Catskill tunnels the average unbalanced head is equal to at least 250 feet and at some points is as high as 425 feet. This enormously increased pressure was the most difficult feature to deal with and one which received exceedingly careful consideration in preparing the design. The result was the establishment of an arbitrary rule that at no point should the sound rock cover for any appreciable distance be less than 150 feet. As a matter of fact, the sound rock cover is materially more than this at practically every point.

The Hudson River crossing. The Hudson River crossing is the most striking example of the pressure tunnel form of construction. The problem of designing suitable apparatus to unwater this tunnel was more difficult than the designing of the tunnel itself. The accepted design consists of two centrifugal pumps of about 5,000,000 gallons combined capacity, each capable of lifting water under a head of about 700 feet and, when arranged in tandem, to raise the water 1100 feet or more, of course with a reduced capacity. This tunnel has been unwatered two or three times with this apparatus with entire success. It is of a portable nature and can be removed to the other pressure tunnels and used in the drainage shafts in a similar way.

Leakage from tunnels. It was anticipated that the leakage from the tunnels in the rock, lined only with concrete, under such high pressures, would be material. It was originally believed that, in the cases of the Rondout and Wallkill Valleys, which are each about 4½ miles across, if each tunnel did not leak more than 1 million gallons daily they would be very satisfactory, probably not greater than from a steel pipe of equal capacity laid in the ground. As a matter of fact, the initial leakage on the first filling was greater, but quickly decreased to a moderate amount and has continued to decrease since, so that the present leakage in all tunnels 36 miles in length, with an interior surface area of 8,700,000 square feet and an average effective outward pressure of 250 feet, is 567 gallons per minute. The leakage of 18 miles is from recent measurements, the

leakage of the city tunnel is estimated from previous measurements. This amount of leakage could be carried through a $1\frac{3}{4}$-inch nozzle under that head.

The city tunnel. A pressure tunnel provided the only reasonable and practicable solution of the delivery of water within the city. The thoroughfares running north and south were already crowded with public utility structures, in the way of gas and electric conduits, subways, etc. Besides this, the inconvenience to the public during construction would have been excessive if it had been necessary to bring this large quantity of water through the city in pipes under the surface. After careful investigations, it was decided to build a pressure tunnel through the backbone of The Bronx and Manhattan Island, crossing the Harlem River, and then the East River to Brooklyn. This tunnel is over 18 miles long, the longest tunnel in the world. This type of construction was also 50 per cent cheaper than delivery by pipes. Contrary to expectation, there have been indications of water at the surface at only two points, at 23d Street and Broadway and at 57th Street and 6th Avenue, and only a very small quantity at each of these points. In cold weather it is most noticeable and at the present time has practically disappeared. One curious matter in connection with the leakage from the tunnels has been observed for at least four years, which is that the leakage varies inversely with the temperature, being at its maximum about March of each year and its minimum the latter part of September, and that both the maximum and the minimum decrease each year. The opportunities for measuring this leakage have been exceedingly favorable, and has been accomplished by measuring in the end shafts of the pressure tunnels at such times as the water is shut off in the aqueduct, this being equivalent to a tank measurement.

When any great project is carried to successful completion, the public likes to believe that one individual is responsible for the success of it, but there is nothing in this view and we all know that success comes, if it comes at all, through the inspiration, confidence and strength, that come with united effort and effective coöperation, on the part of all connected with it. It is certain that any success which may have been achieved on this work is due more to the quality and character of the individuals in the organization than to their leaders. What has contributed most to the effective conduct of the work has been the almost uniform belief and confidence in

one another, the high sense of loyalty and the willingness to sacrifice personal ambition and preferment for the good of the work. All held the good of the work above every other consideration. The policy has been to work with the contractors—not against them; to help and not to hinder. Any other policy means an economic waste. None have been more loyal or more conscientious, or have contributed more to the success of the work.

The author does not claim that this organization has had a monopoly of loyalty, but he does believe that the ties that bind have been a little stronger and more flexible, the sacrifice of personal ambition has been greater and that the loyalty has been more spontaneous and effective. It is certain that association for years with an organization of this character is worth more than any honor or personal preferment which might possibly come to any one, due to his connection with it and its successful completion.

Acknowledgment should be made of the cordial coöperation which has been given by the successive city administrations and by all the men connected with the coördinated departments of the city government with whom we have come in contact. All have been willing to grant the privilege of a hearing at all times. The author desires particularly to acknowledge the very complete coöperation of the chief engineers of the department of water supply, gas and electricity, Mr. de Varona, Colonel Smith and Mr. Brush, and also of the members of their organizations. They have gone out of their way, in season and out of season, to assist in every possible manner. It would have been wrong to have had any other relations between these two departments which are so closely concerned with the water supply of the city, one having to do the planning and construction of the additional supply, which, on completion, devolved on the other department for maintenance and operation.